Acquisition and Analysis of Data in a Pressurized Entrained-Flow Coal Gasifier for the Purposes of Simulation Validation

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Outline

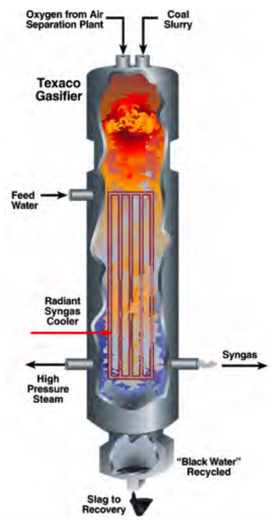
- Introduction
- Background – coal gasification research
- U. Utah pilot-scale coal gasifier
- Types of data available for validation
- Performance issues
- Uncertainty considerations
- Conclusions

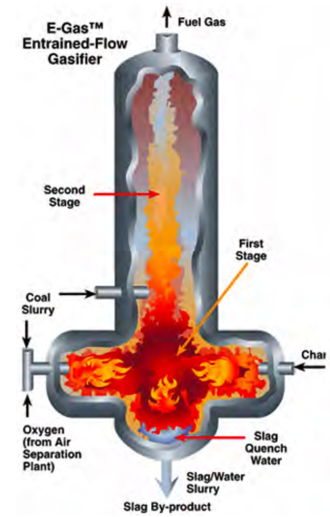
Introduction

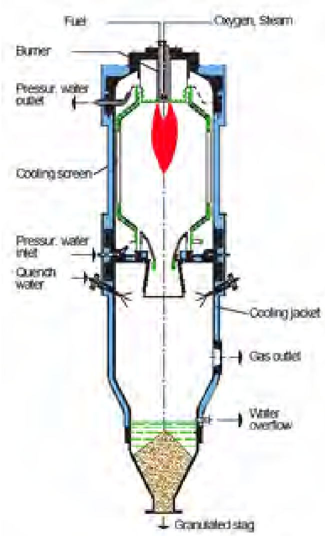
- Industrial-scale coal gasifiers are primarily pressurized, O2-blown, entrained-flow variety
- Cost of gasification systems provides strong incentive to optimize using computational simulation
- Access to gasifiers for acquisition of validation data is challenging

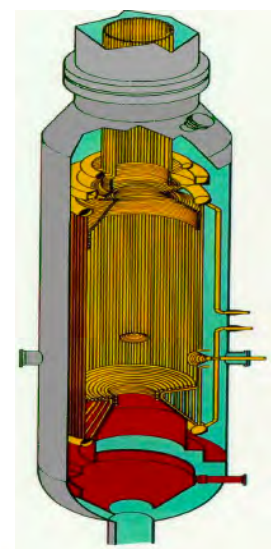
Pressurized O_2-Blown Entrained-Flow Gasifiers

	Downflow	Upflow
Refractory-Lined	GE Energy	ConocoPhillips
Membrane Wall	SIEMENS	Shell Global Solutions





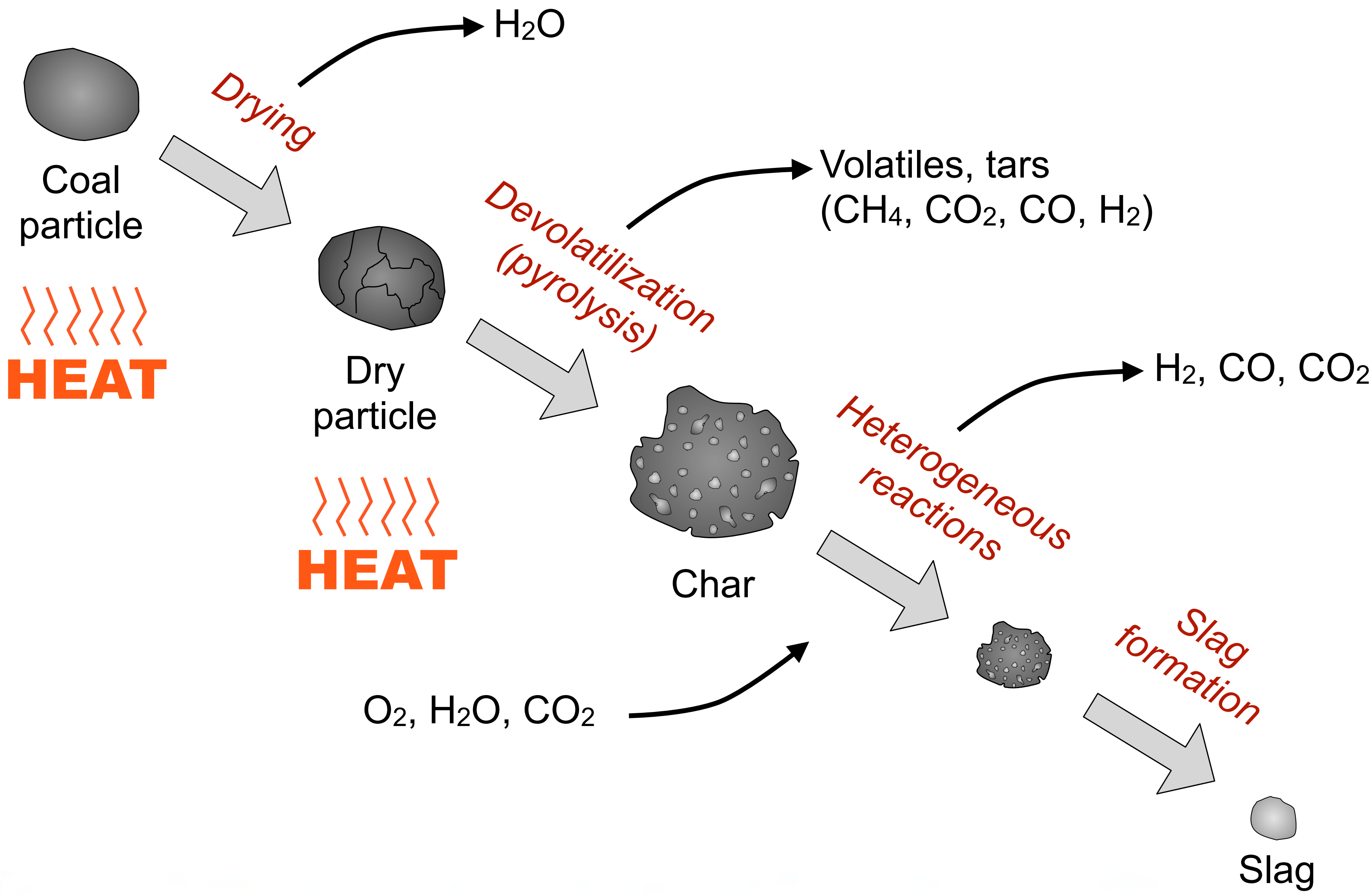




Challenges of Validation Data Acquisition

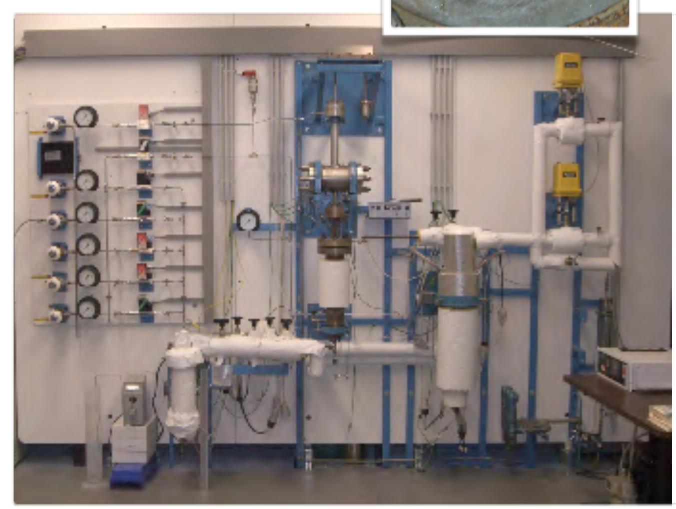
- High temperature
  - 1300-1500°C at reactor exit
  - In excess of 2000°C within oxy-coal flame
- High pressure
  - IGCC application typically 25-30 atm (400 psi)
  - Chemicals / fuel production 70+ atm (1000+ psi)
- Corrosive environment
  - Reducing environment
  - Gaseous sulfur species (H_2S, COS)
  - Molten coal slag
- Consequences
  - Crossing pressure boundary for gas sampling creates safety concerns
  - Thermocouples typically last only a few days

Fundamental Coal Gasification Studies



Experimental Evaluation of Coal Conversion

- Drop tube (entrained-flow) furnaces
  - Pyrolysis yields
  - Char gasification kinetics
  - Physical transformations of coal particles
- Wire mesh heaters
  - Pyrolysis yields
- Thermogravimetric analyzers (TGAs)
  - Heterogeneous char gasification kinetics
- Mini-gasifiers
  - Electrically heated
  - Gases (CO_2, O_2) supplied from laboratory cylinders



"Small" versus "Big"

- Fundamental Studies ("small")
  - Up to perhaps 2 kg/day in entrained-flow reactors
  - Bottled gases
  - Electrically heated
- Commercial-Scale Systems ("big")
  - Hundreds of tons of coal (petcoke) per day
  - Oxygen-blown, with all associated mess
  - Difficult to access
- Need "medium" scale system to bridge this gap of 5 orders of magnitude

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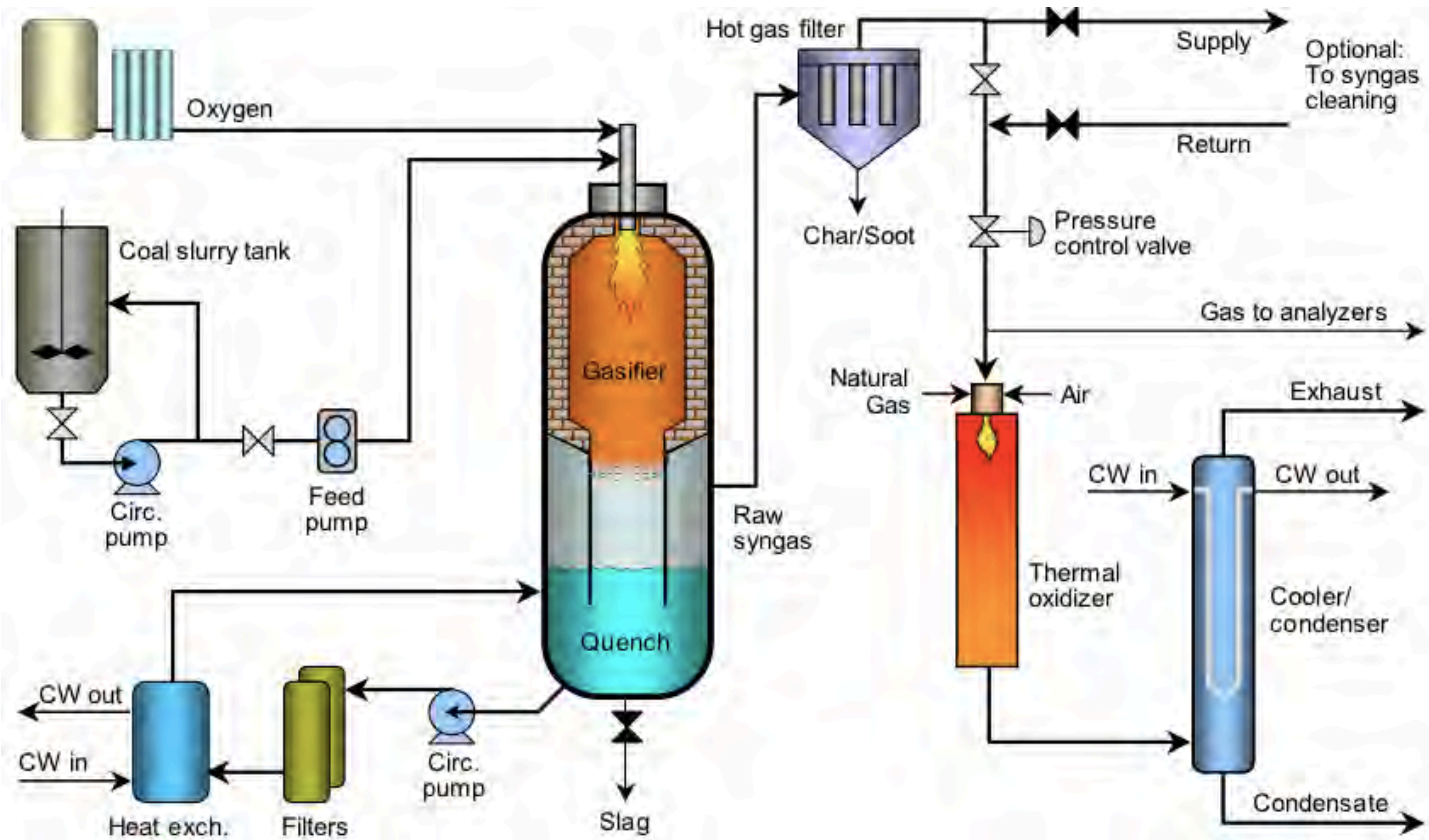
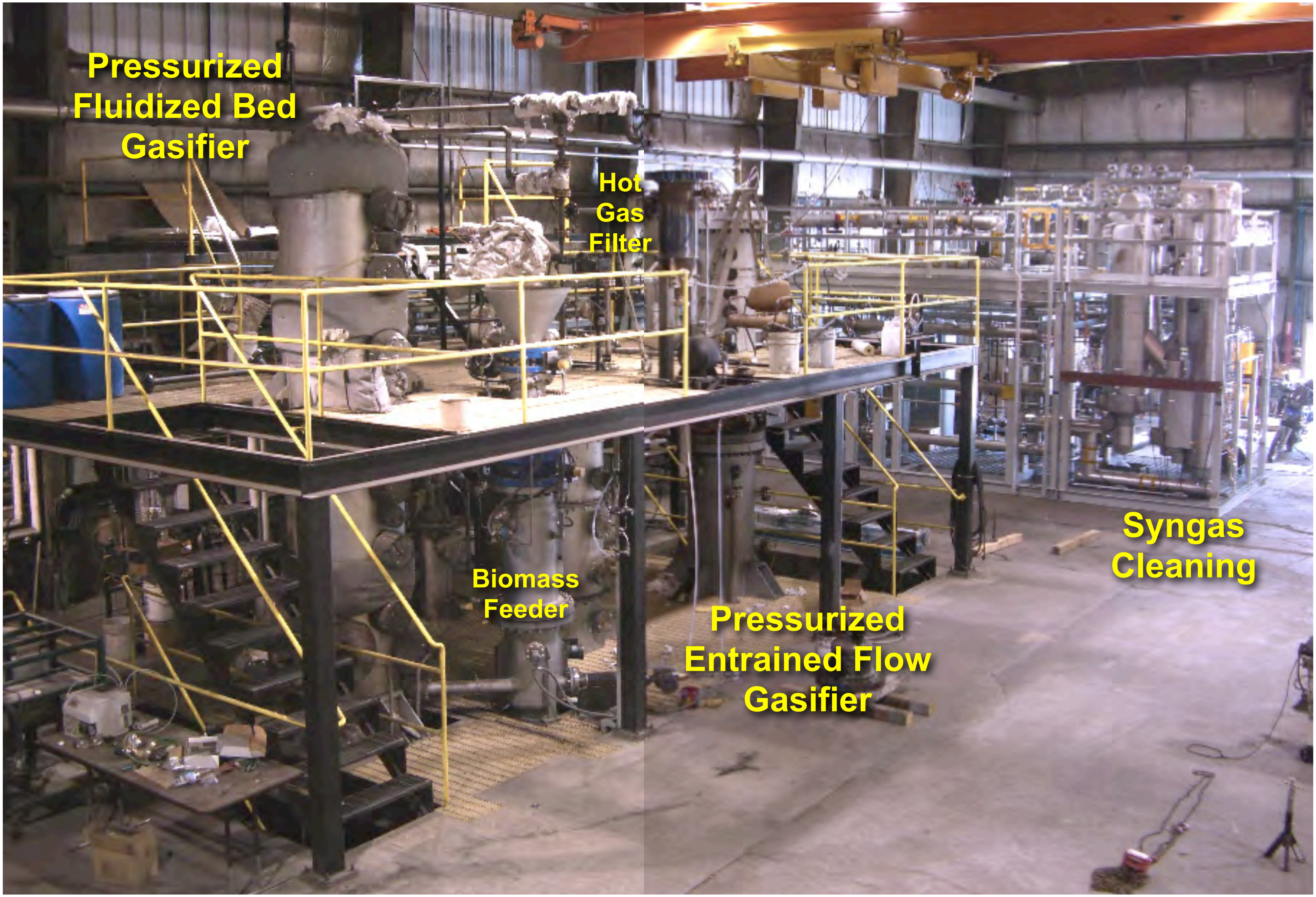
Bridging the Gap: UofU Gasifier

- Designed to operate like a "large" system
  - No electrical heating
  - Only inputs are oxygen and coal (slurry)
  - Similar in design to a GE gasifier
- Accessible like a "small" system
  - Reactor "stretched out" to decrease diameter and allow sampling at multiple residence times
  - Several (six) sampling ports down length of reactor
  - Six thermocouples for temperature measurement

Gasifier System Schematic



Gasification Research Laboratory



Entrained-Flow Gasifier

Oxygen Supply System

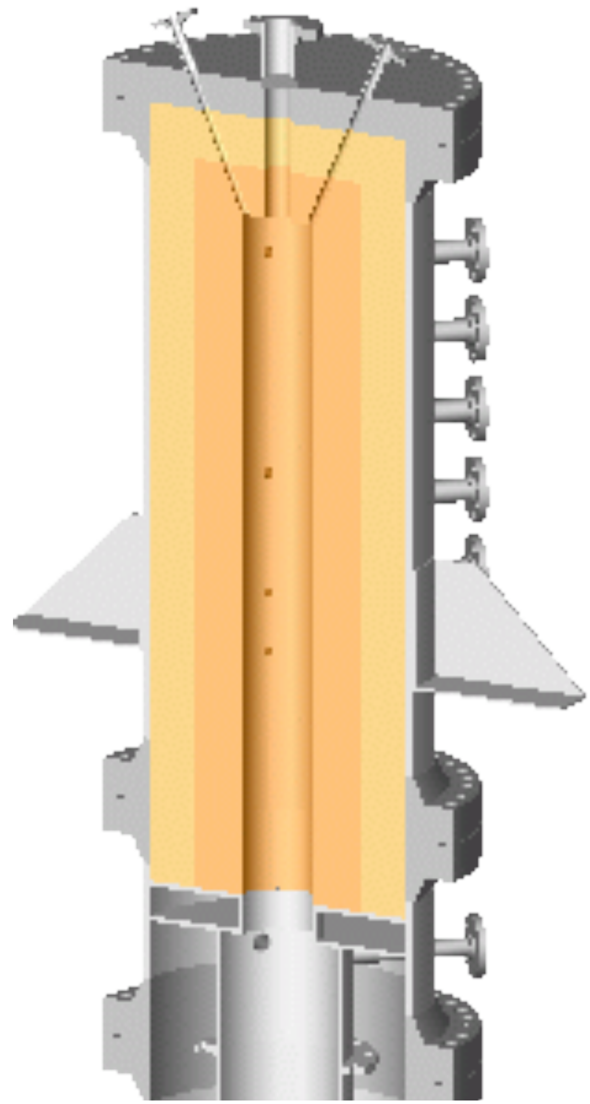
- On-site oxygen tank
  - 6,000 gallons / 20 tons
  - Serves gasification and oxy-fuel systems
- “Trifecta” system to boost pressure
  - 325 psi
  - Limits standard operation pressure to ca. 260 psi
  - Higher pressures require auxiliary high pressure supply
- Flow control system to gasifier
  - Pressure regulator
  - Control valve
  - Coriolis flowmeter

Gasifier Specifications

Parameter	Typical	Max.
Pressure (bar)	18	31
Temperature (°C)	1425	1700
Slurry feed rate (lit/h)	50	150
Coal feed rate (kg/h dry)	30	80
Thermal input (kW_{th})	220	600
Slurry concentration (wt%)	59	65
Oxygen feed rate (kg/h)	35	150
Syngas production (m^3/h dry)	50	150

Reactor Details

- Reactor dimensions
  - 30 inch (0.75 m) pressure vessel
  - 8.5 inch (0.22 m) reactor ID
  - 60 inch (1.5 m) reactor length
  - Designed to identify development of gas and condensed phases as coal undergoes conversion
- Sample ports
  - Twelve opposing 2 inch (5 cm) ports at six levels for sampling, optical diagnostics
  - Two additional 2 inch (5 cm) ports at burner level
  - Six 1 inch (2.5 cm) ports for temperature/ pressure measurement



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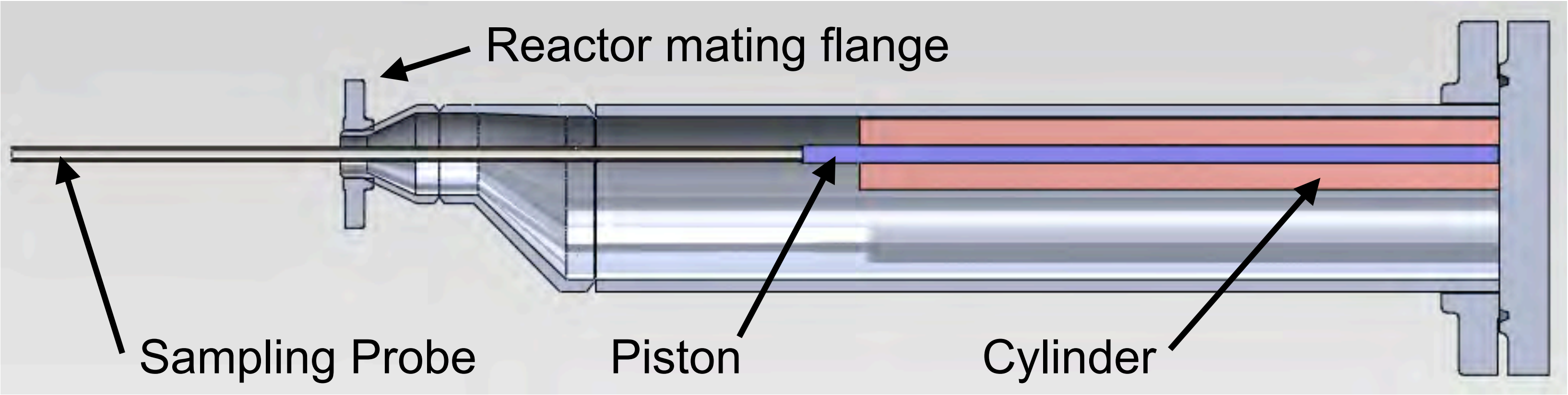
The Easy Stuff

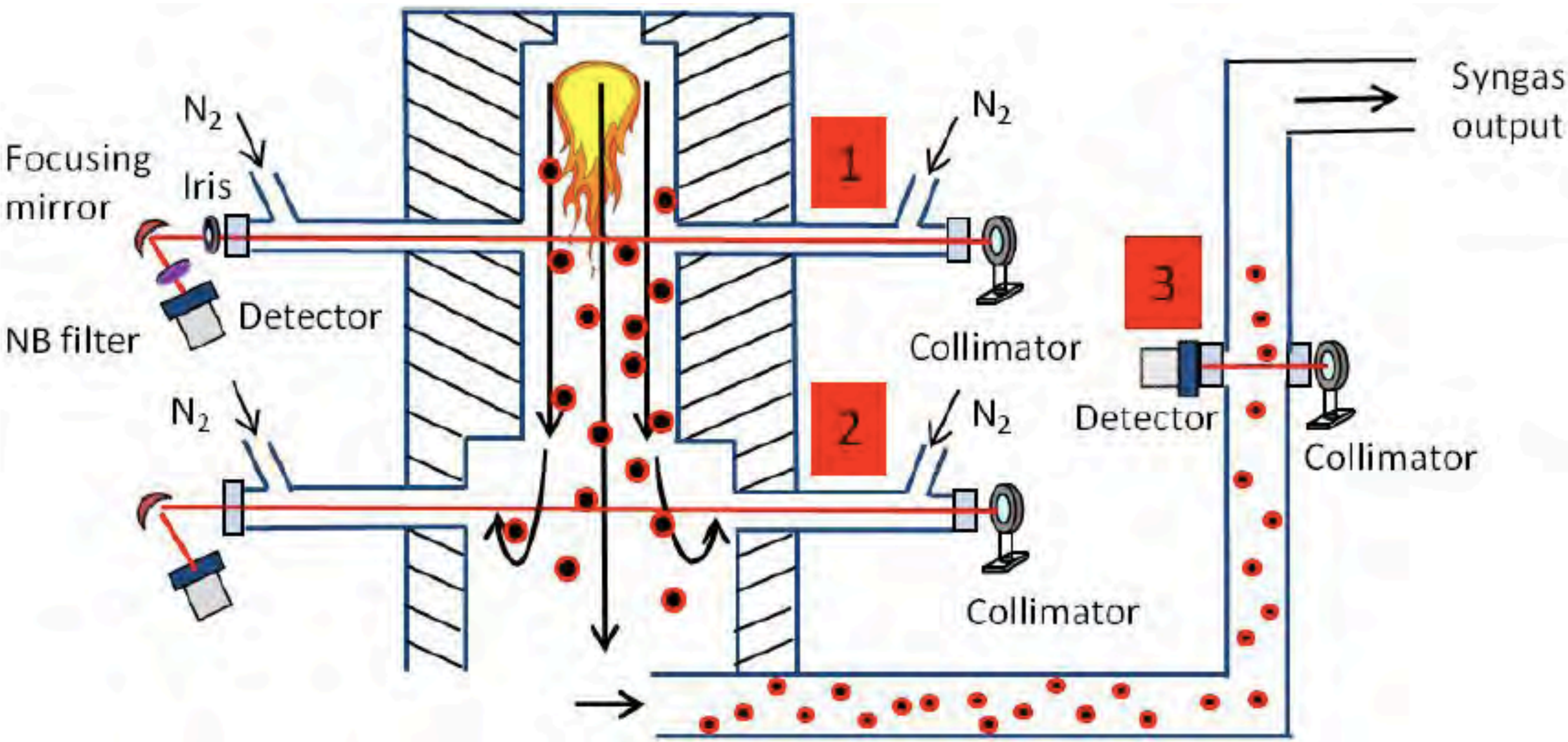
- Inputs
  - Slurry flow rate and concentration
  - Coal composition
  - Oxygen feed rate
  - Purge flow rates
- Temperatures
  - Five B-type thermocouples along length of reactor
  - Additional thermocouples in quench, on shell, etc.
- Syngas composition
  - Analysis after gas has been quenched, cooled, depressurized
- Solids composition
  - Char caught in filters, slag caught in slag trap
  - Analyzed only after system is depressurized

Extractive Sampling

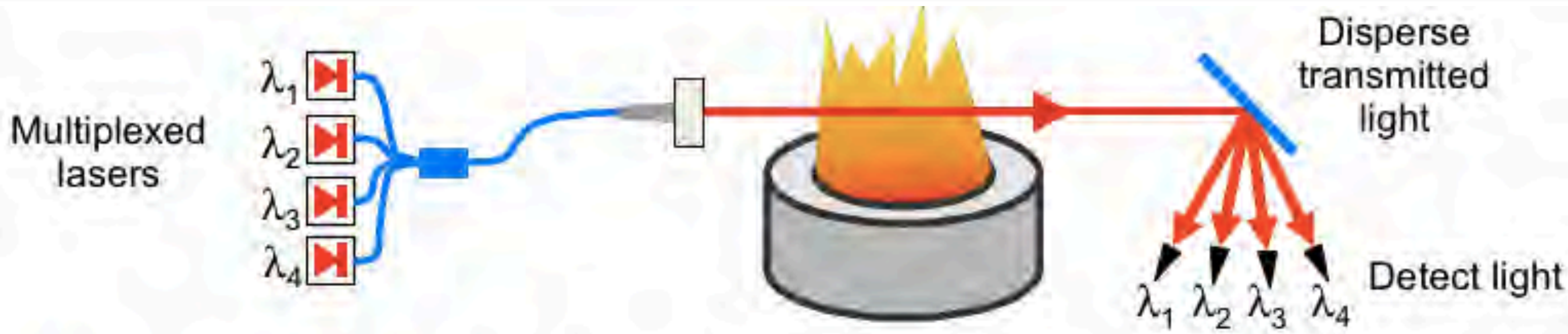
- Cooled probe for gas sampling within reactor chamber
- Moveable piston will allow quick positioning from wall to centerline of reactor
- Safety systems integrated with gasifier control system
- Can be installed at any of five locations down length of reactor
- Modification of system will allow deposition of condensed-phase material onto probe



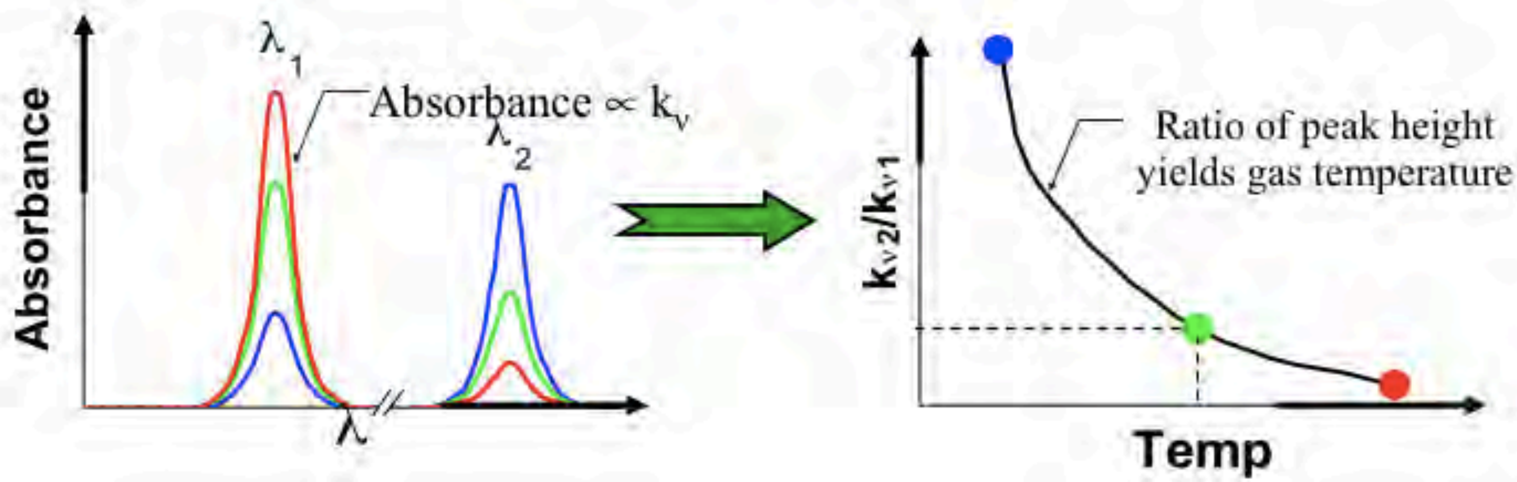
Measurement Locations for Stanford TDL Sensor Project



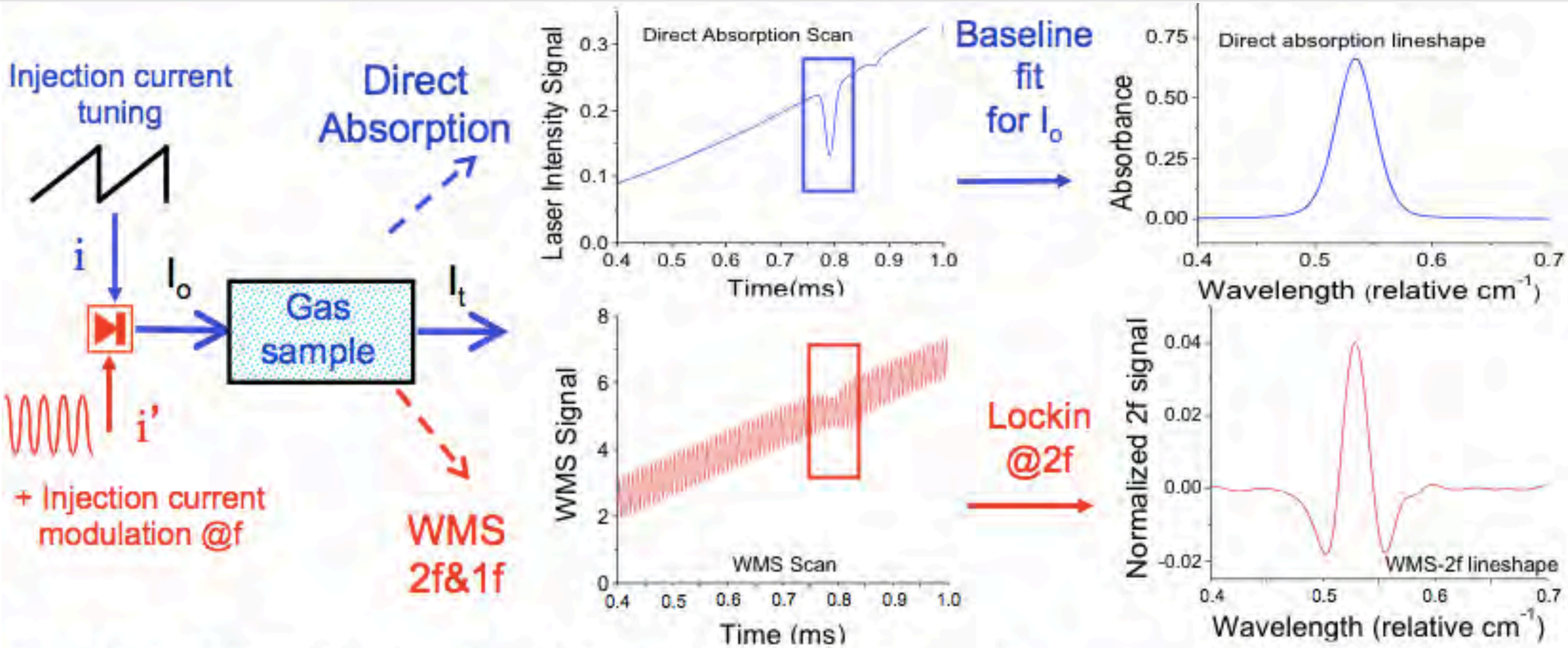
Absorption Fundamentals: Wavelength-Multiplexed Tunable Diode Laser Sensing



- Absorption of laser light by molecular transitions in the combustion gases
  - Beer's law: Transmission = $I/I_o = e^{-kL}$
  - Absorption coefficient k = f(temperature, pressure, gas composition)
- Ratio of absorbance on two molecular transitions yields gas temperature
- Multiplex additional lasers for more combustion species

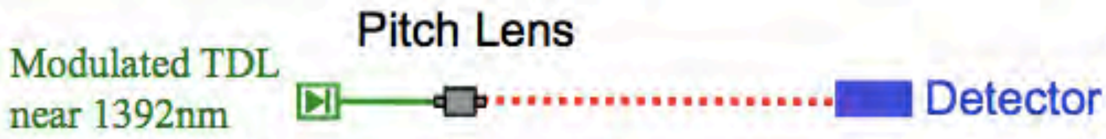


Absorption Fundamentals: Scanned Direct Absorption and Wavelength Modulation Spectroscopy

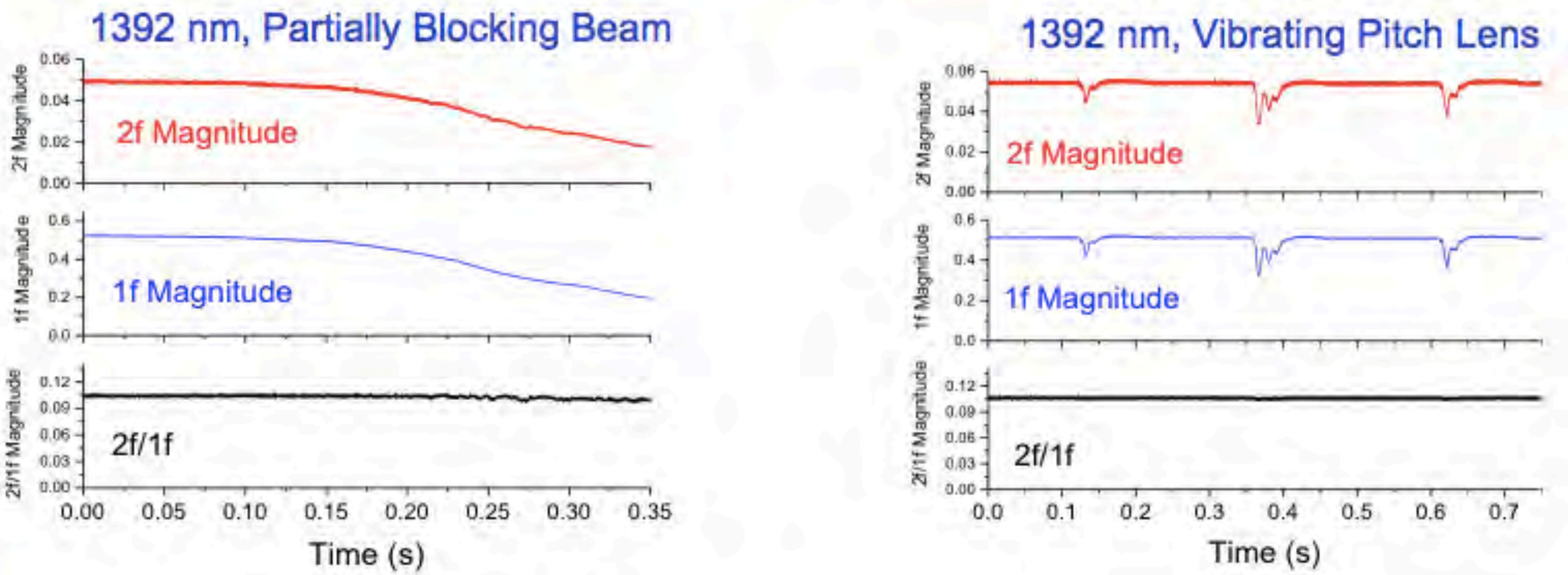


- Direct absorption: Simpler, if absorption is strong enough
- WMS: More sensitive especially for small signals (near zero baseline)
  - Ratio of two WMS-*2f* signals provides T (same as direct absorption)
  - WMS with TDLs has improved noise rejection (especially for non-absorption losses)
  - WMS also produces intensity modulation @*1f*
  - *Since both 2f and 1f signals are proportional to I; 2f/1f **independent** of optical losses*

Absorption Fundamentals: Demonstration that Normalization of WMS Improves Signal-to-Noise Ratio



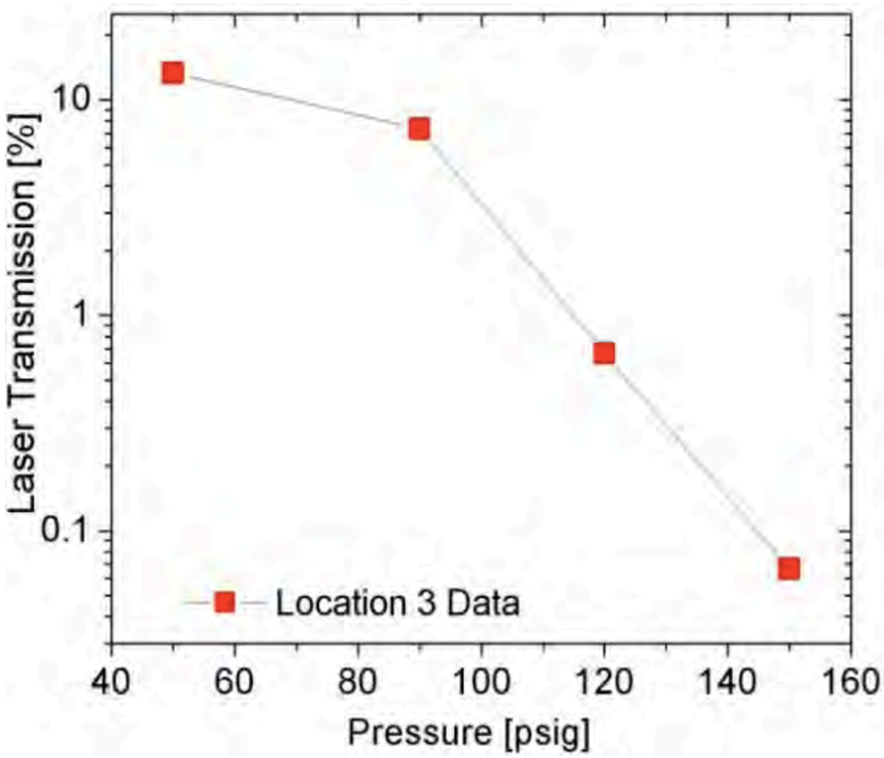
- Fixed I WMS-*2f/1f*
- Ambient H_2O (T=296 K, 60% RH)
- L=29.5 cm, ~6% absorbance)



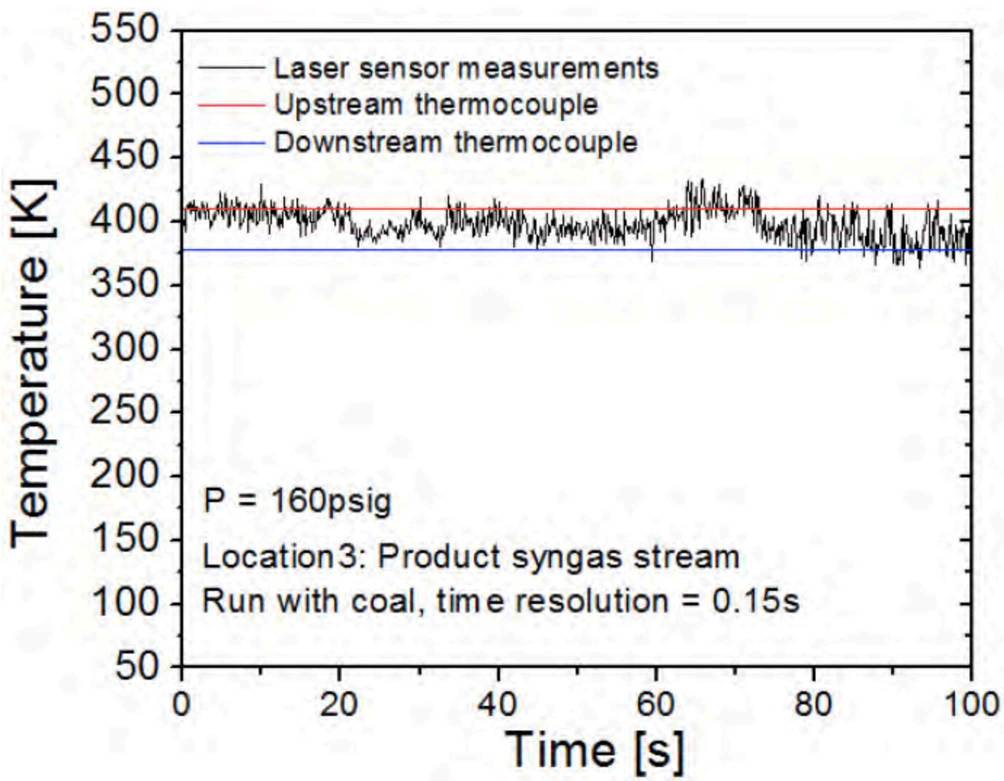
- Demonstrate normalized WMS-*2f/1f*
  - No loss of signal when beam attenuated (e.g., scattering losses)
  - No loss of signal when optical alignment is spoiled by vibration
- Normalized WMS-*2f/1f* signals free from window fouling and particulate loading

TDL Sensor Results at Position 3

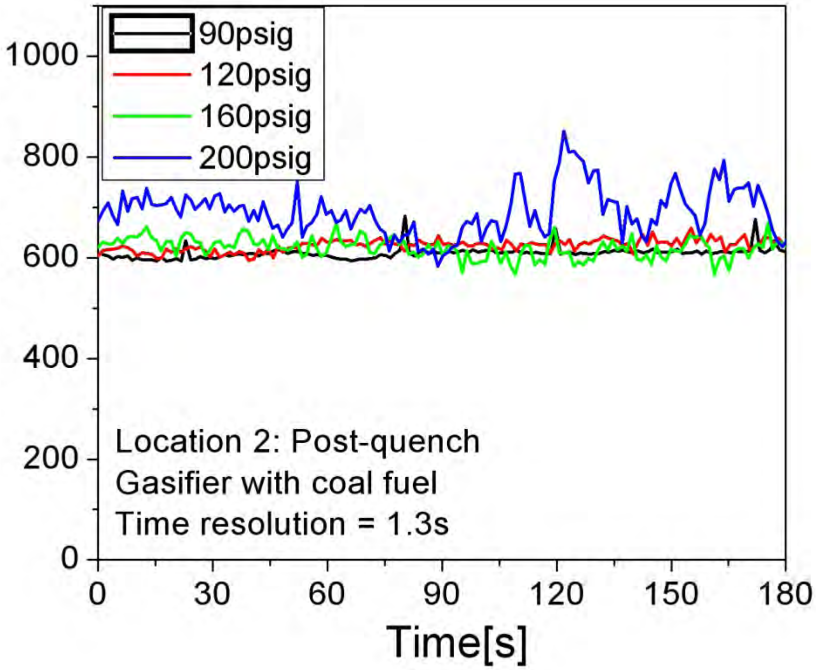
Laser Transmission vs. Pressure

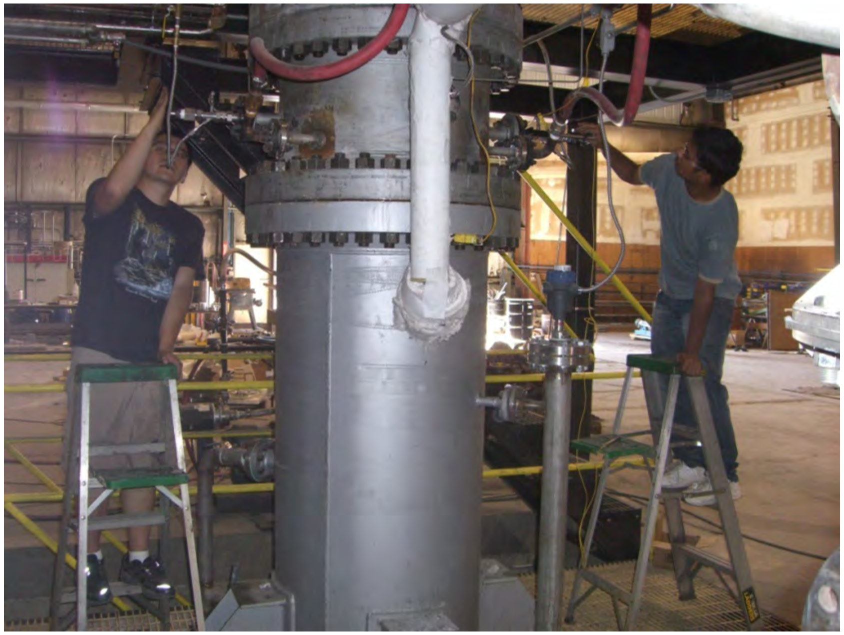


Measured Temperature at 160 psi



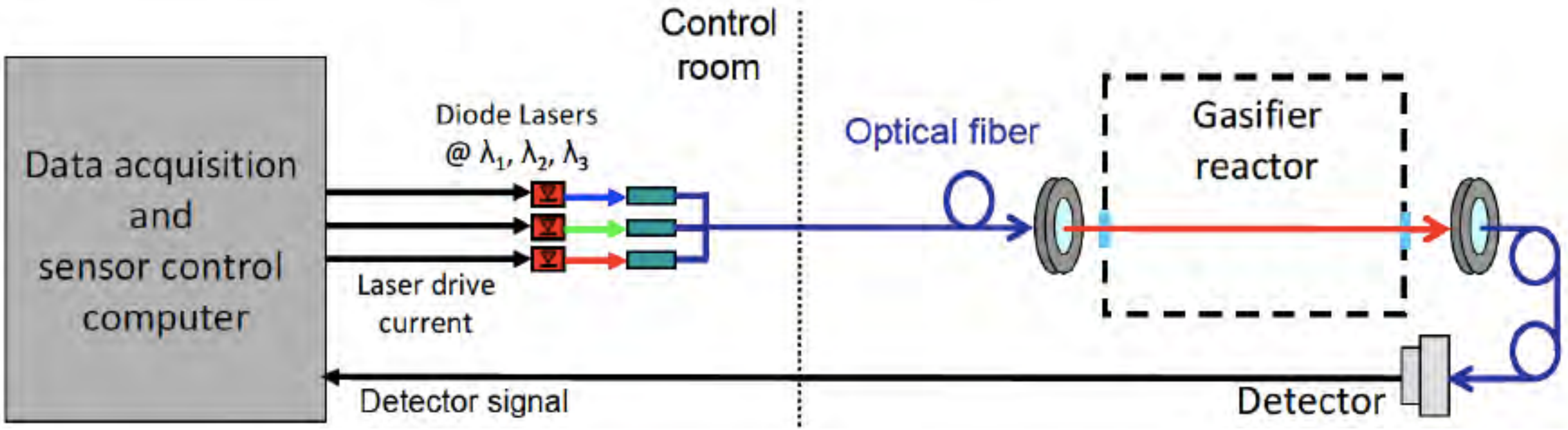
TDL Sensing at Position 2

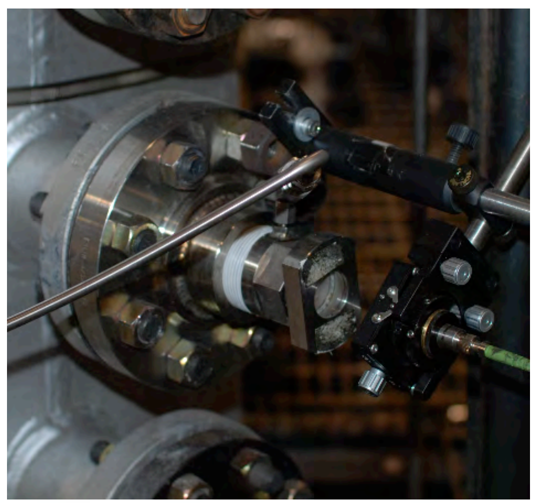


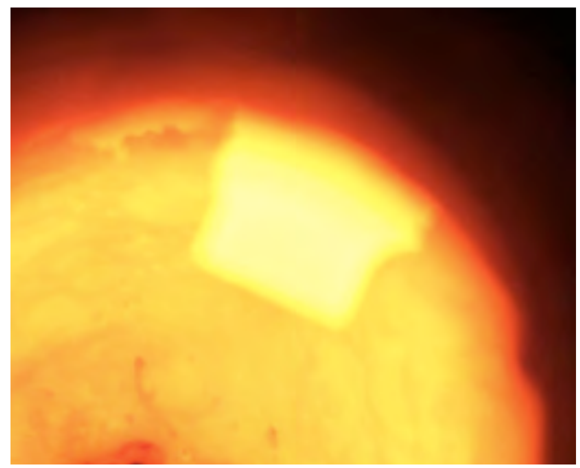


- High SNR, time-resolved measurements of T
- Normalized WMS accounts for varying transmission
- Measured T at reactor pressures of 90, 120 and 160psig stable
- Measured T at 200 psig identifies potential spray splashback instabilities

TDL-Based Measurements within Reactor "Core" (Position 1)







Validation Data Summary

Conditions

- To 500 kWth
  - 1.5 ton/day coal
- 440 psia (30 atm) pressure
  - Typically operate at psia
- Temp to 3100°F (1700°C)
  - Typically 2400-2600°F
- Various fuels
  - Pittsburgh #8
  - Illinois #6
  - Utah Sufco
  - Texas Lignite
  - Petcoke

Measurements

- Wall temperature
  - 5 positions
- Syngas composition
  - Post-quench
  - Pre-quench
- Reactor temperature
  - Integrated TDL-based
- Internal gas composition
  - Extractive sampling
  - Integrated TDL-based
- Internal condensed-phase
  - Extractive sampling

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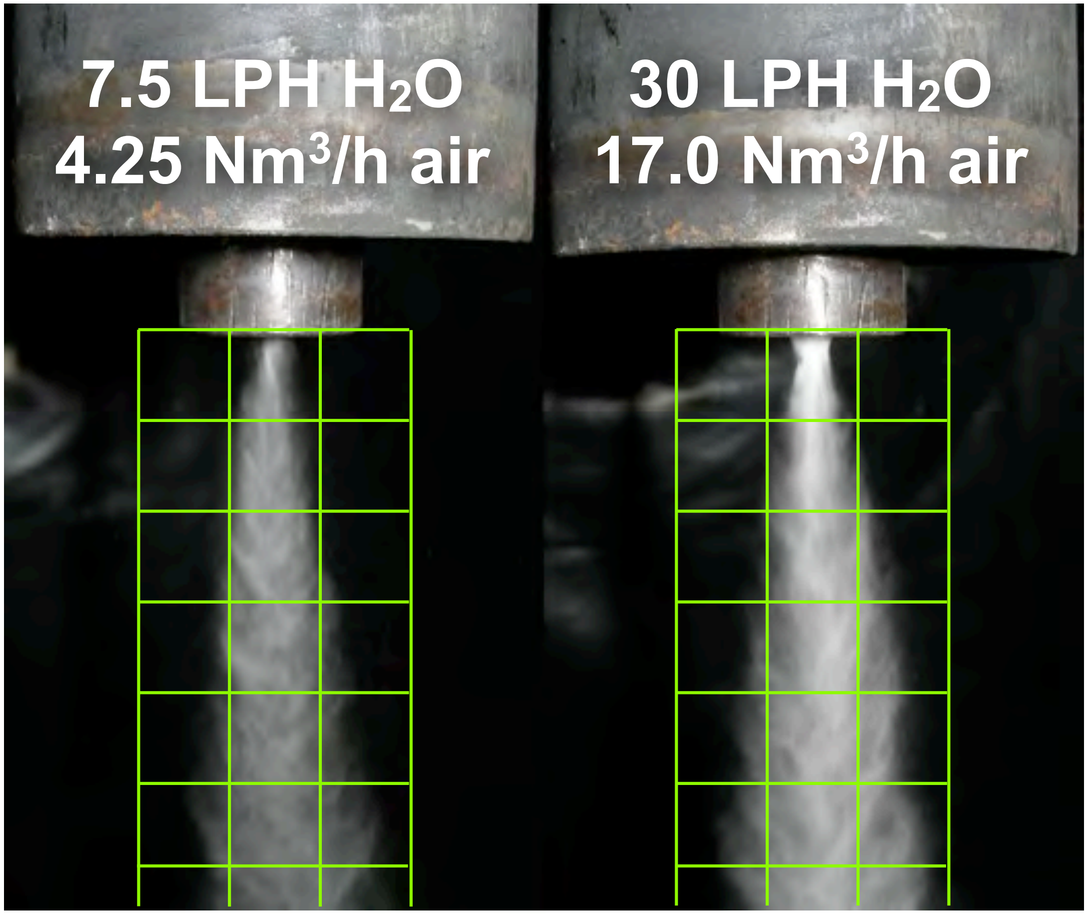
Injector Cold Flow Test System

- Identification of injector performance
  - Uniformity
  - Spray angle
  - Droplet size
- Full scale model
  - Uses same injector as actual reactor
  - Air instead of oxygen
  - Water instead of slurry
- Pressurized system (to 5 bar) under development
- Analytical methods under development

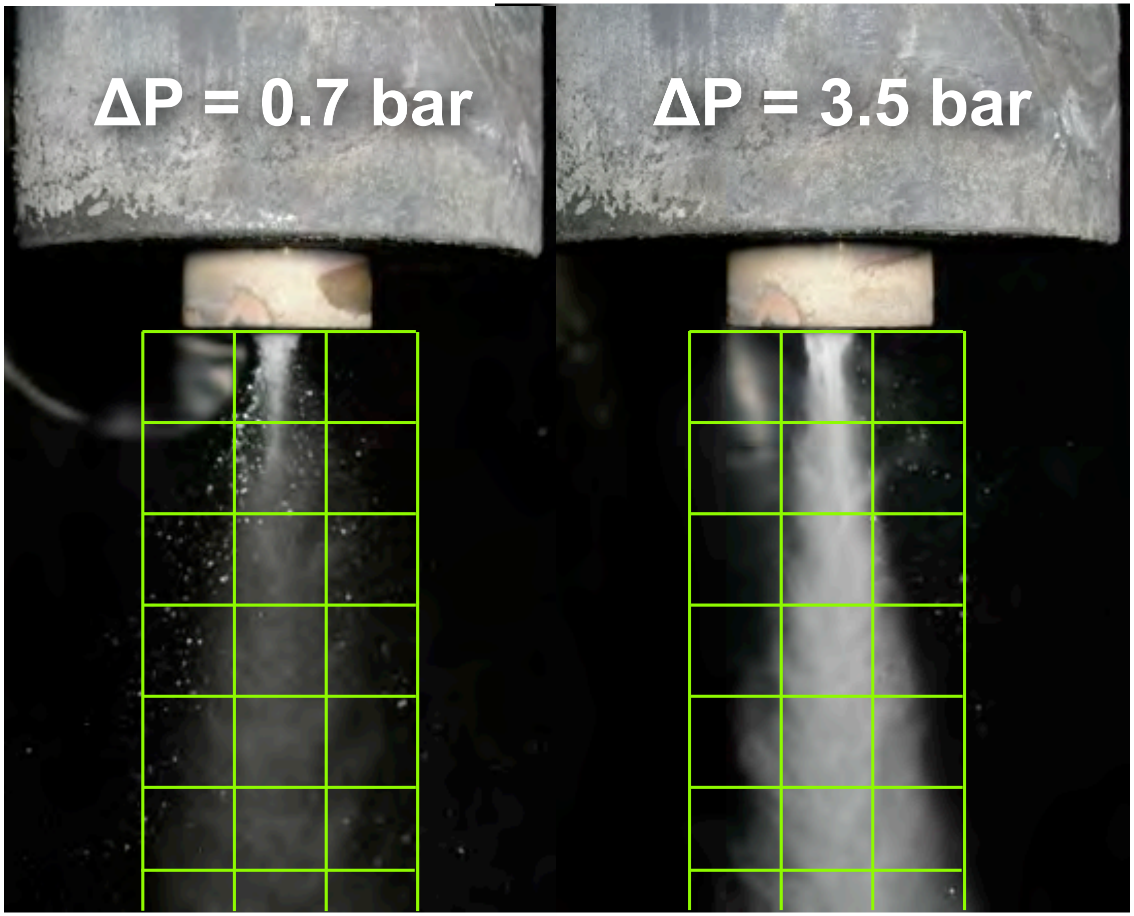
Flow Rate

Flow rates of air and water adjusted simultaneously to maintain air/water ratio
Air pressure drop 2.8 bar
45 degree nozzle

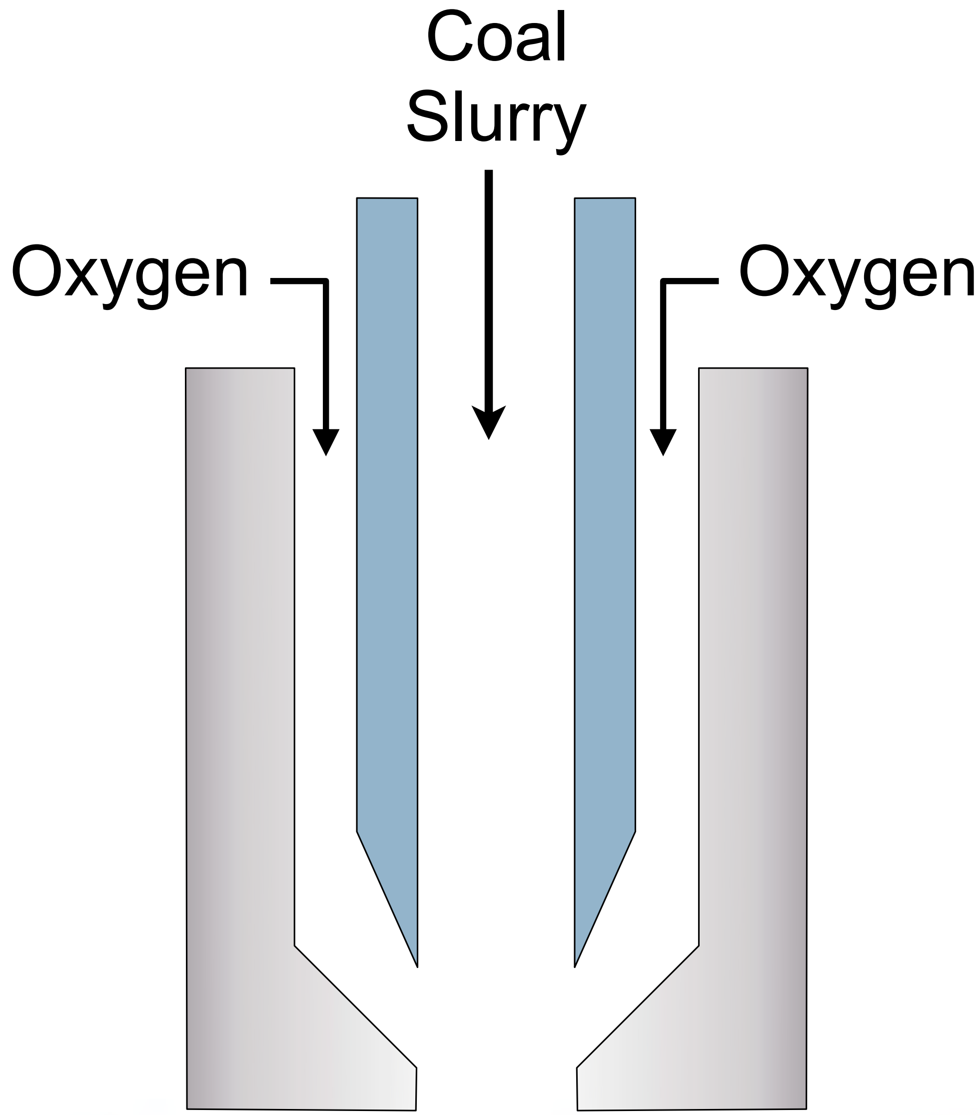


Pressure Drop

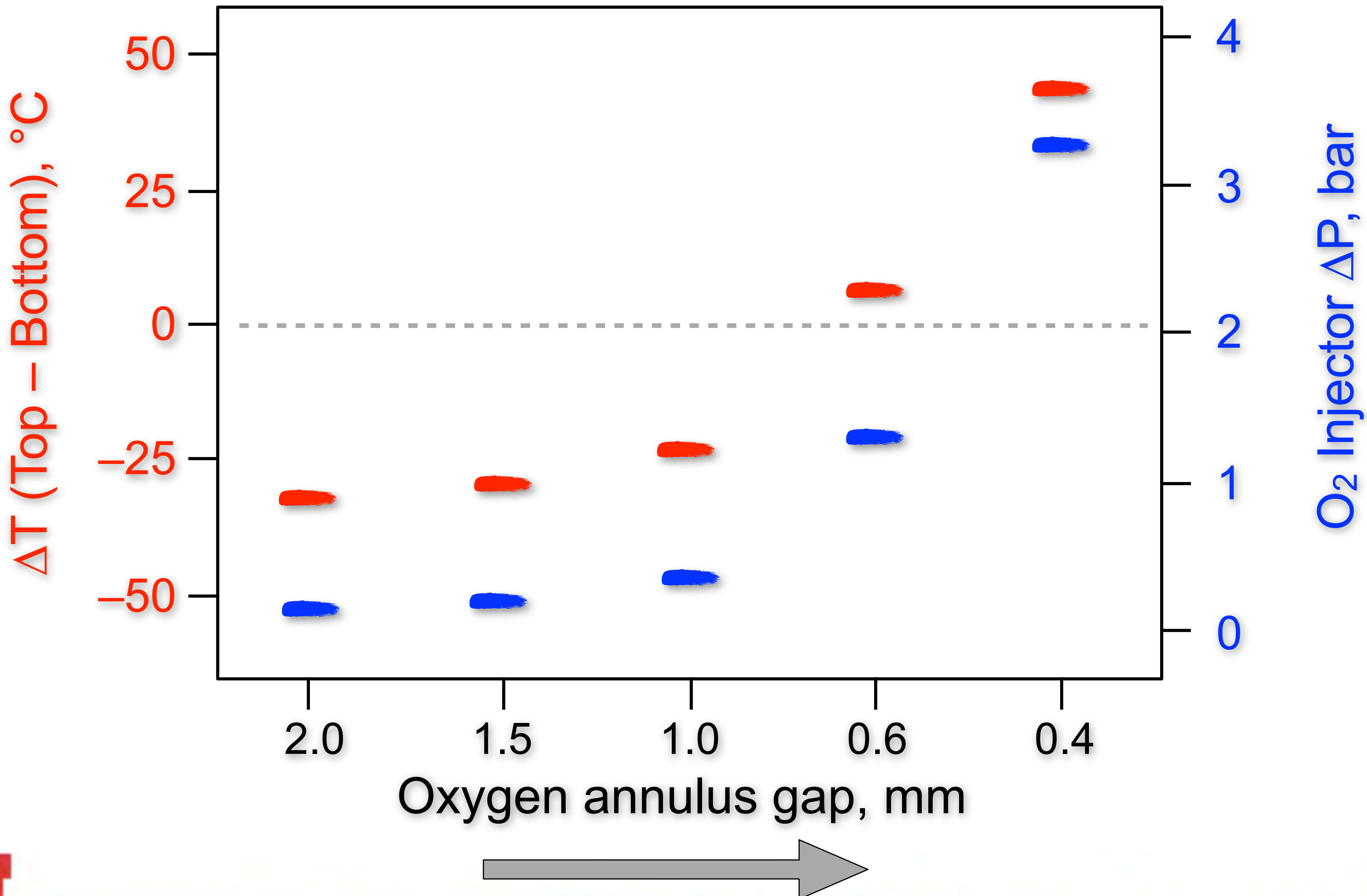
Both cases have 30 LPH water feed, 17 Nm^3/h air feed
65 degree nozzle



Adjustable Injector Tip

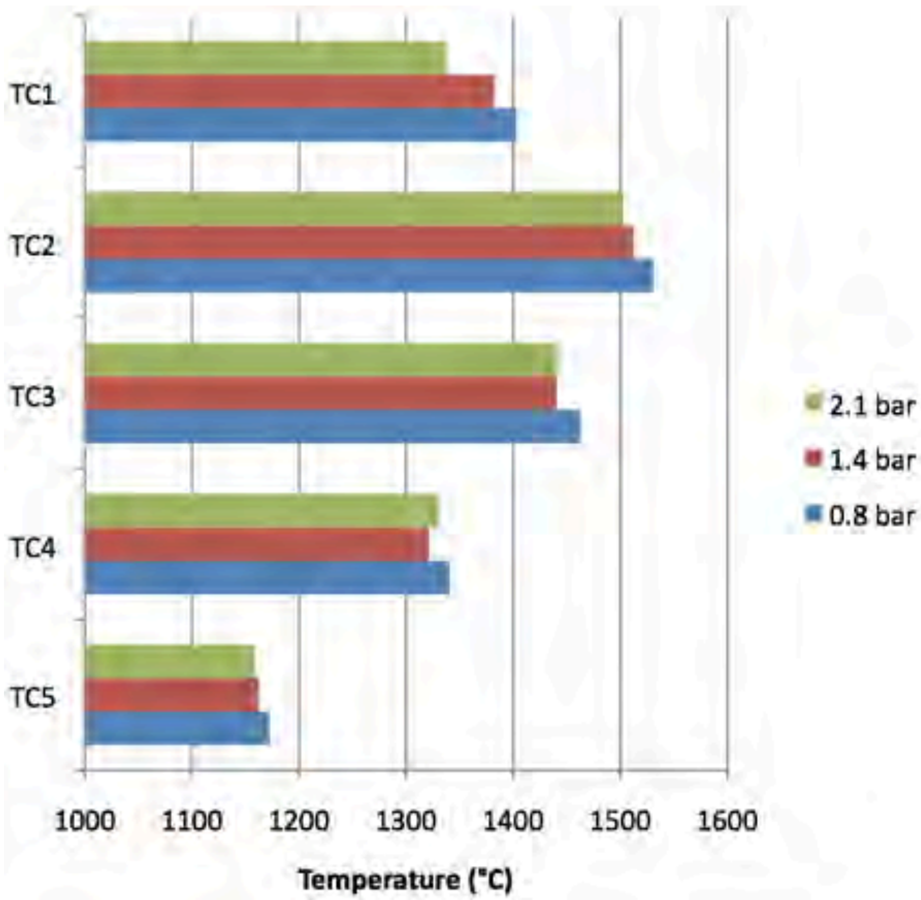


Performance vs. Injector Gap

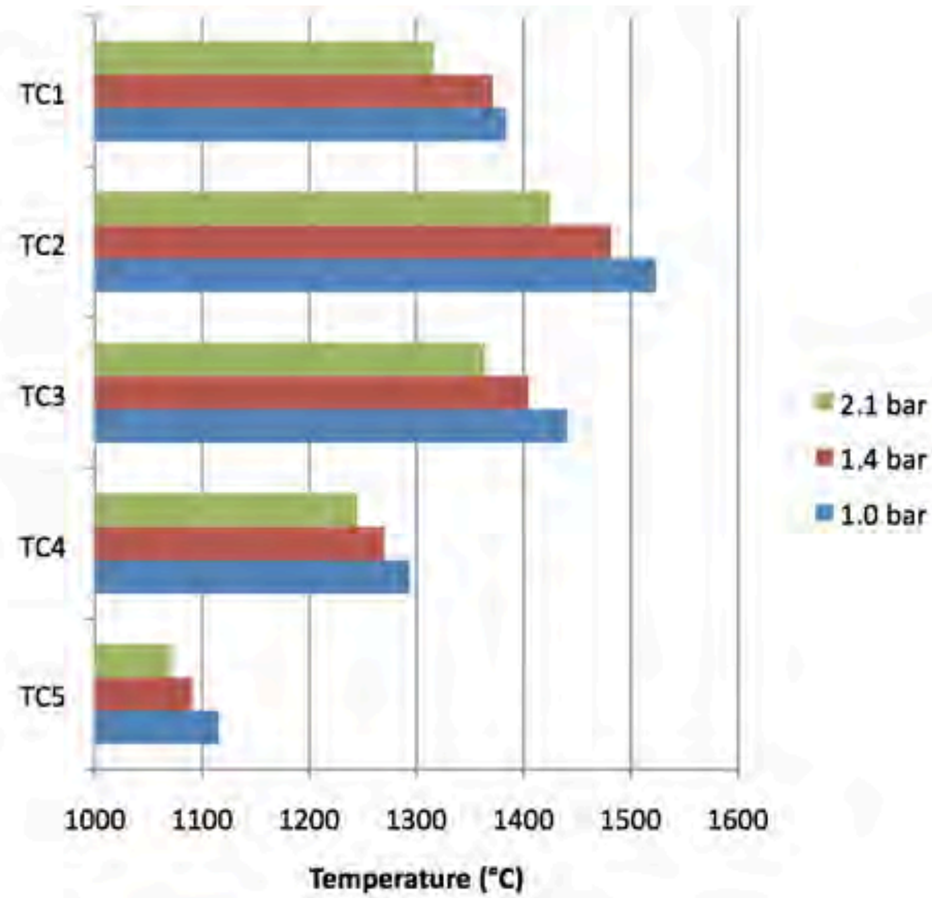


Temperature Profile

45° nozzle angle (Day 1)

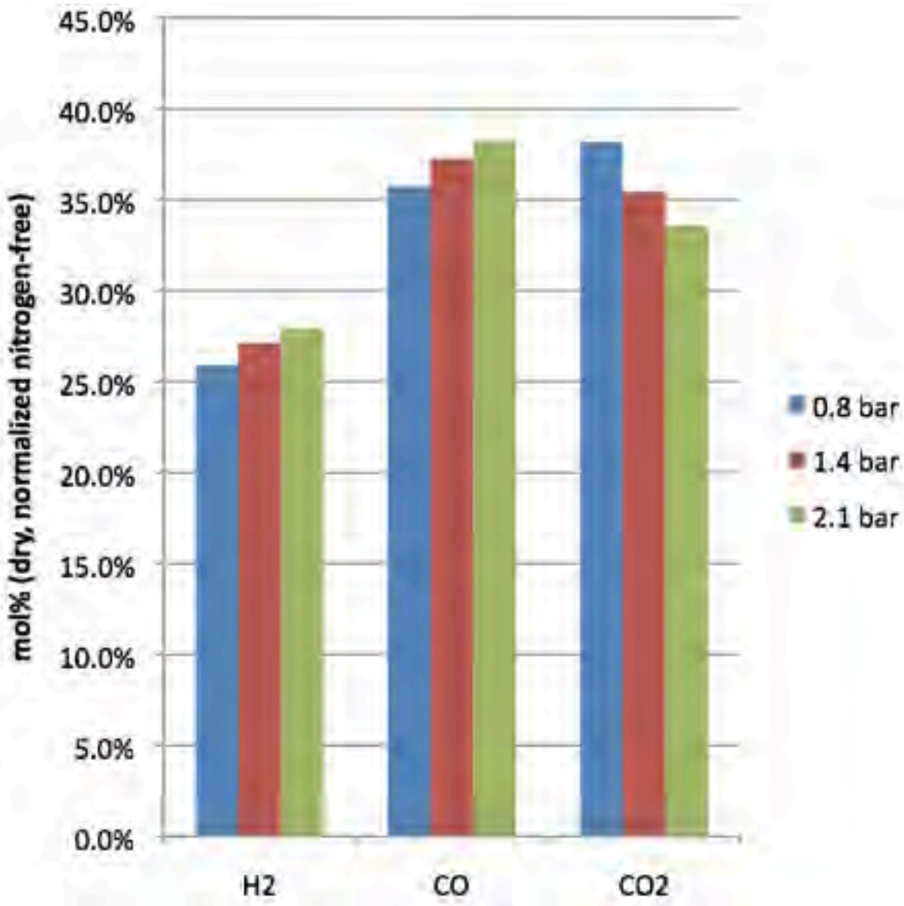


65° nozzle angle (Day 2)

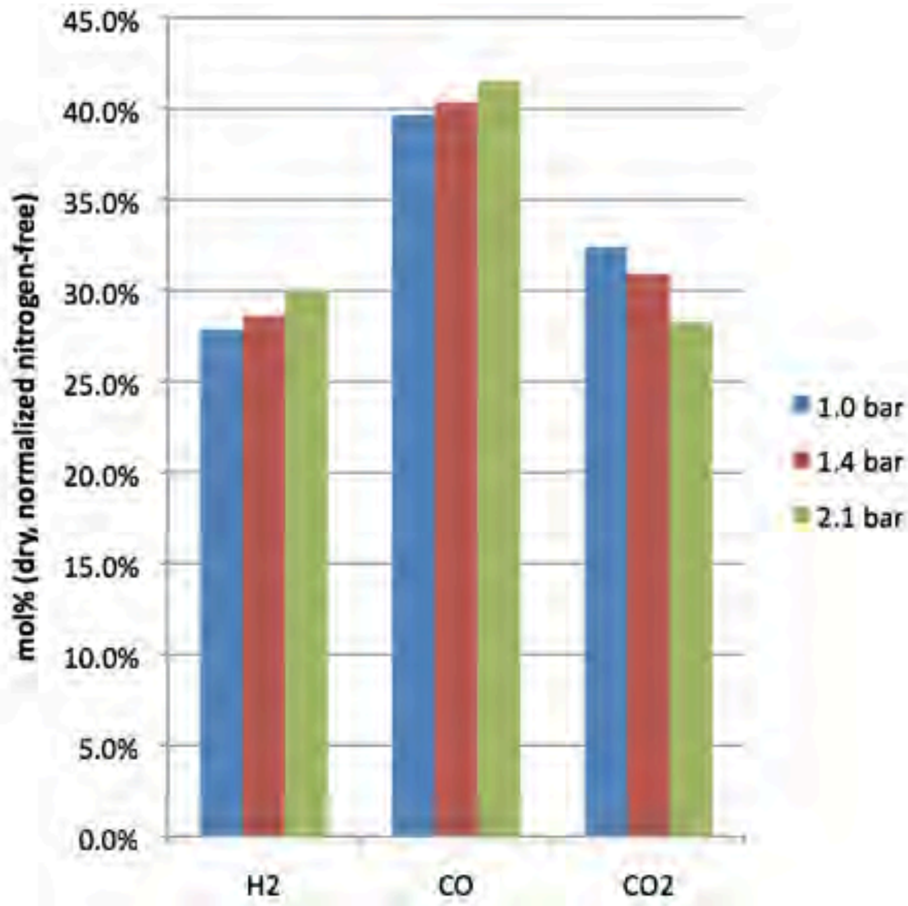


Syngas Composition

45° nozzle angle (Day 1)



65° nozzle angle (Day 2)



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Uncertainty Considerations

- **Temperatures:** Thermocouple junction located within wall, approx. 0.5 inch from refractory face, to extend thermocouple life
- **Gas composition:** Cooling within extractive probe may affect gas composition due to:
  - Changes in gas equilibrium composition at lower temperatures
  - Absorption of minor constituents (sulfur compounds, ammonia) by condensed water
  - Condensation of e.g., polyaromatic hydrocarbons as gas is cooled

Uncertainty Considerations (2)

- **Condensed-Phase Material:** Difficult to obtain instantaneous compositions. Must be aggregate over time.
- **All Data:** Fluctuations on various time scales need to be quantified
  - 2 seconds
  - 20 minutes
  - Day-to-day

Conclusions

- Acquisition of data within reaction zone of pressurized gasifier very challenging
- Gasifier performance strongly tied to injector design and efficiency of fuel distribution
- Optical techniques offer unique opportunity for real-time non-invasive sampling
- Quantification of data variation and associated uncertainty is important if data is to be used for validation of simulations

Acknowledgements

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